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The destination has only a limited amount of buffer memory it can store new segments in

If the application is not reading the data as fast as it arrives, the buffer will fill up

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If the space left is very small, the sender can slow down sending until space in the receiver is freed up

TCP

Flow Control

A

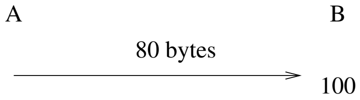
B

100

Initially B has space 100 in its buffer

TCP

Flow Control



A sends 80 bytes

TCP

Flow Control

A

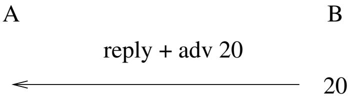
B

20

B save the data in its buffer

TCP

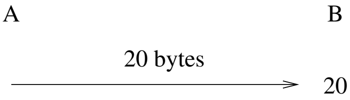
Flow Control



On the next returning segment, B advertises 20

TCP

Flow Control



A now knows it shouldn’t send more than 20

TCP

Flow Control

A

B

0

Next advertisement would be 0

TCP

Flow Control

A

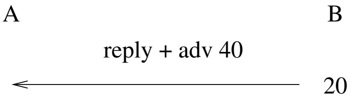
B

40

Until B reads some of the data

TCP

Flow Control



And can advertise the space

TCP

Flow Control

Thus B can tell A to slow down or speed up as appropriate to its remaining buffer space

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The other flow control mechanism to deal with varying conditions in the network comes later

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- Checksum of the header, the data, *plus some fields of the IP layer*

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Again, bad design!

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The urgent pointer is a pointer into the data stream that indicates where the current *urgent data block* ends

Urgent data includes things like interrupts that need to be processed before any other data that is buffered

TCP

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The OS interrupt code would then read through the urgent data block and act appropriately on what it finds there

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This flag says send the buffered data to the application, don't wait

TCP

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The idea here is that there is no point for the receiver waiting for more data, as there is no more to send right now

TCP

After the fixed header there are the options, including *window scale* and *maximum segment size*

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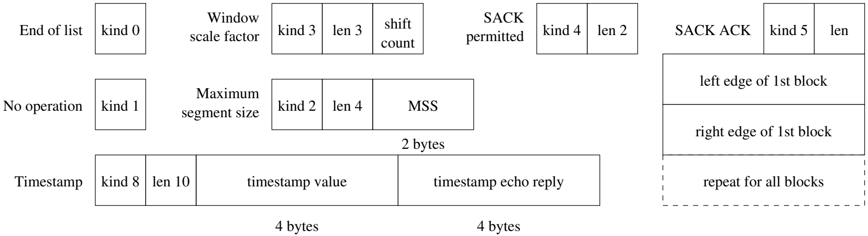
After the options header is the data, which can be empty, e.g. for a pure ACK

TCP
Options

TCP Options are many and varied



Some TCP optional headers

TCP

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Maximum segment size (MSS) specifies how large a segment we can cope with: the headers are not included in count

TCP
MSS

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The MSS is usually communicated in the option header in the setup of the TCP connection, and is typically set to avoid fragmentation

TCP

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A large window is very important is modern fast networks to get the most out of the available bandwidth: we don't want the client to have to keep stopping to wait for the server

My desktop uses a window scale of 7: $2^7 \times 65535 = 8388480$ bytes, or a maximum of 8MB buffer space per connection

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Exercise Go back and re-read the section on advertised windows

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Timestamp (TS val) puts the time of day into the segment header, allowing accurate measurement of the *round trip time* (RTT) of a segment and its ACK. Useful for computing retransmission times (see later)

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Timestamp Echo Reply (TS ECR) in an ACK segment is the timestamp being returned to the sender so it can compute the RTT

Selective acknowledgement (SACK) is an extension of the ACK mechanism that allows more flexible ways of acknowledging segments. SACK is negotiated in the connection setup with a *SACK Permitted* option

TCP
Options

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This is because some things, e.g., buffer space, need to be set up before a connection and varying them mid-connection is difficult or makes little sense

TCP

Setup and Teardown

TCP is *connection oriented*, meaning a connection is set up between source and destination, and all packets that flow within this connection are related, through the sequence numbers, and they all use the same state, such as advertised window

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It is important to realise that this is a connection in the *transport layer*

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The underlying layer, IP, is not connection oriented, and each individual datagram is treated individually, e.g., might take a different route to its destination: IP is *connectionless*

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Thus TCP connection has a weak version of sessions: though no further session mechanism is provided, e.g., no session resumption

TCP

Connection(less)

UDP is not connection oriented. Each datagram in UDP is treated individually

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Of course, both connection oriented and connectionless protocols are useful in the right circumstances

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Fortunately for the application programmer, all this detail is taken care of by the TCP layer software in the operating system: though it does have occasional repercussions in the application if the connection needs to outlive the application for a while

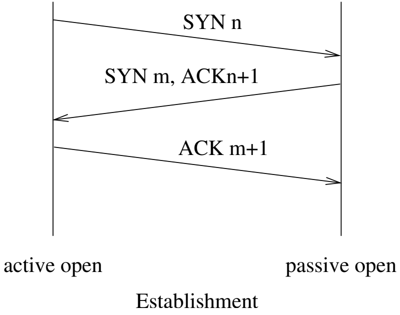
TCP

Setup and Teardown

Before TCP can send data, it exchanges some packets with the setup information

TCP

Setup and Teardown

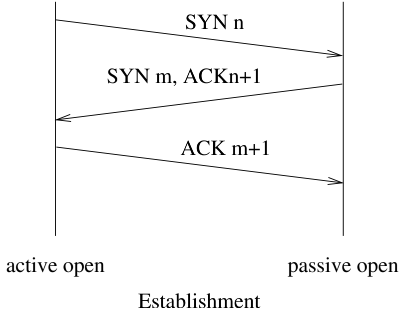


TCP setup handshake

Three segments are needed to exchange the information needed to make a new connection;

TCP

Setup and Teardown

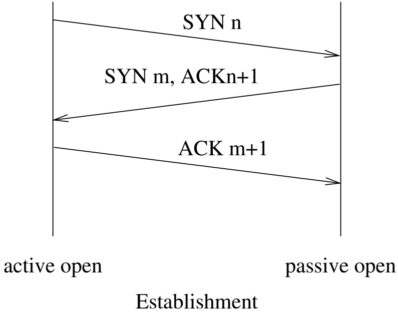


TCP setup handshake

The initiator, the *client*, sends a segment with the SYN flag set and its *initial sequence number* (ISN), *n*, is randomly generated;

TCP

Setup and Teardown

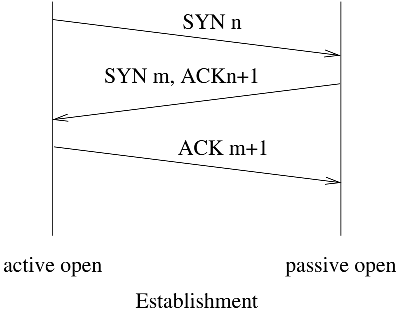


TCP setup handshake

The receiver, the *server*, replies with another SYN segment containing its own ISN, *m*;

TCP

Setup and Teardown

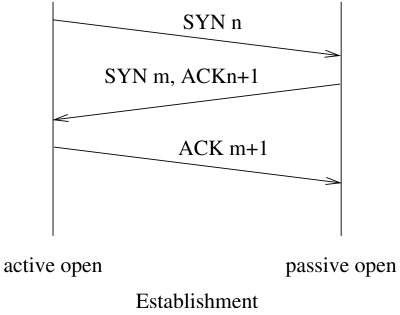


TCP setup handshake

It also ACKs the client's ISN with $n+1$, the sequence number of the next byte it expects from the client;

TCP

Setup and Teardown

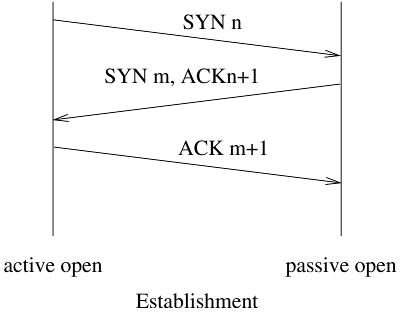


TCP setup handshake

The initial SYN can be lost just like any other segment, so we need to ACK it independently of the first data byte, which comes later;

TCP

Setup and Teardown



TCP setup handshake

The client ACKs the server's ISN with $m + 1$

This is called a *three way handshake*

TCP

Setup and Teardown

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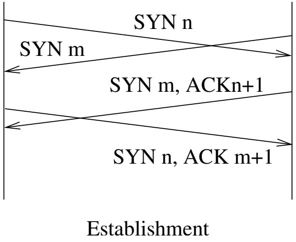
The client (first one to initiate) is said to do an *active open*, while the server does a *passive open*

TCP

Setup and Teardown

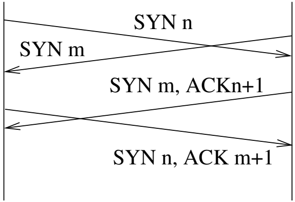


TCP simultaneous open

It is possible (but rare) for *both* hosts to do an active open, where the SYNs cross each other in flight

TCP

Setup and Teardown



Establishment

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Matching TCP port numbers will identify when this happens

TCP

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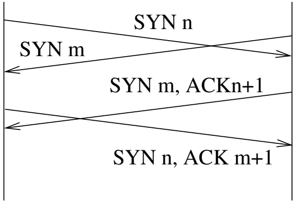

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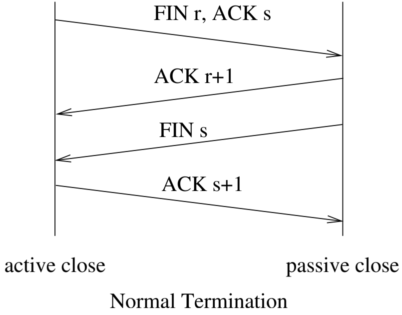
This is defined to produce *one* new connection, not two

TCP

Setup and Teardown

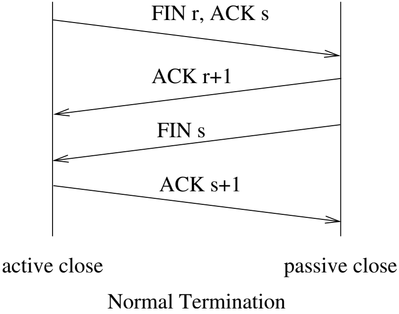


TCP teardown

Closing a connection takes up to four segments;

TCP

Setup and Teardown

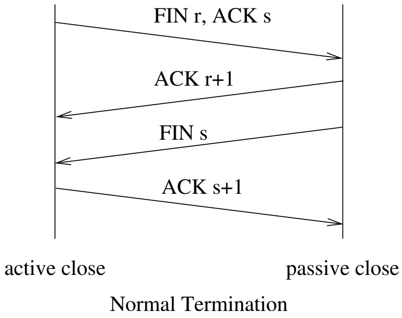


TCP teardown

TCP is full duplex, and a connection in one direction may be closed independently of the other;

TCP

Setup and Teardown

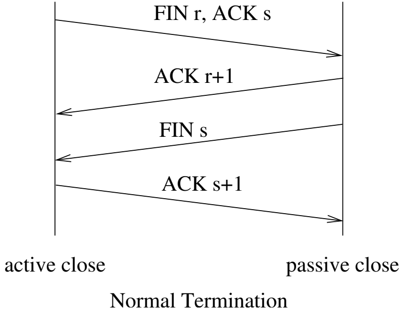


TCP teardown

The FIN flag is set to indicate a *half close*: this indicates no more data will be sent from this end;

TCP

Setup and Teardown

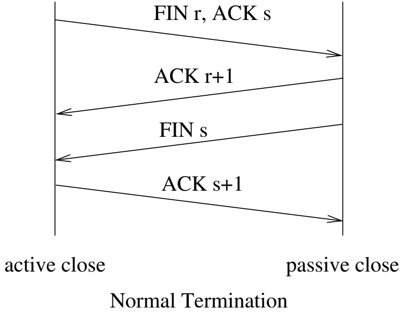


TCP teardown

We can still *receive* data at this end;

TCP

Setup and Teardown

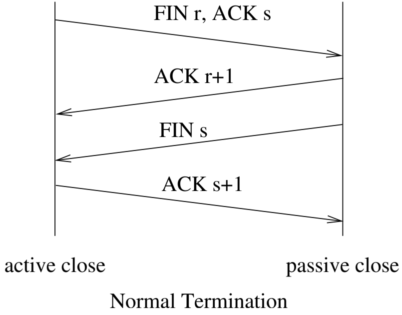


TCP teardown

The FIN is ACKed;

TCP

Setup and Teardown

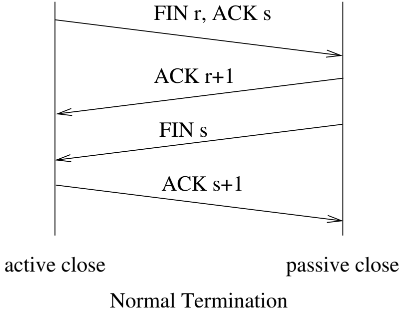


TCP teardown

When the other end wants to close, it sends a FIN and gets an appropriate ACK;

TCP

Setup and Teardown

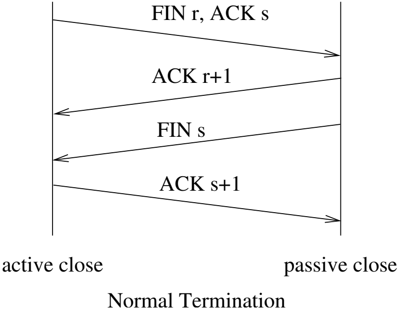


TCP teardown

Note there may still be data (and the corresponding returning ACKs) flowing from the server to the client before the server decides to close;

TCP

Setup and Teardown

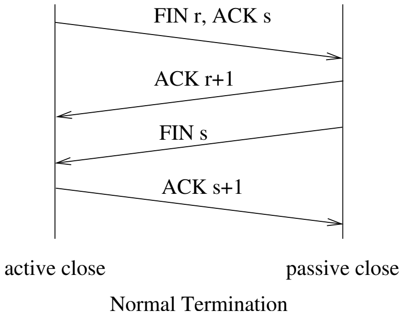


TCP teardown

The first close is called an *active close*;

TCP

Setup and Teardown

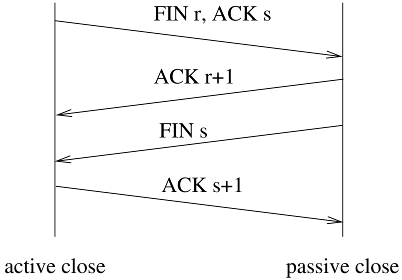


TCP teardown

The other end does a *passive close*

TCP

Setup and Teardown



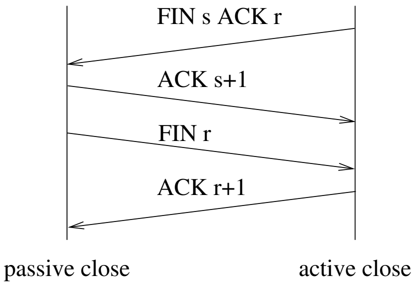
Normal Termination

Active close from left

Either end can initiate the active close; it does not need to be the host that did the active open

TCP

Setup and Teardown



Normal Termination

Active close from right

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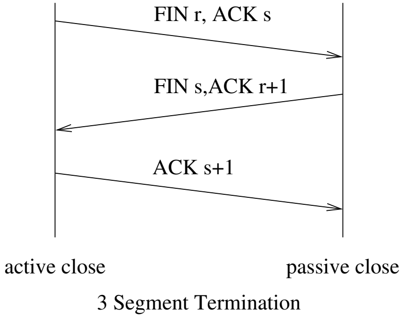
TCP

Setup and Teardown



Three segment close

The passive close FIN can be piggybacked on the ACK: this then takes only three segments

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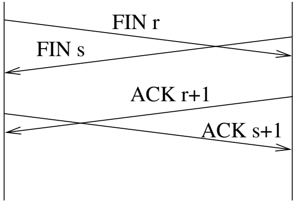

Termination

Simultaneous active close

There can (rarely) be a simultaneous active close: this takes four segments again

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For example, if a server crashes and reboots while the client is still sending the server will not know what to do with the segments it is receiving; so it replies with a RST

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Termination

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Often seen by the application as a “connection reset by peer” message

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Exercise Think about the security aspects of this: a third party can inject a RST segment into a connection to kill it